Effects of tissue mobilisation from lactating sheep on the growth of lambs

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Abstract of a Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Agricultural Science.

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Tissue mobilisation by ewes during lactation and its association with suckling lamb growth was examined. The study was conducted at the Lincoln University sheep unit from September to December 2015 using ewes that all gave birth to lambs but then reared with no lambs (n=9), one lamb (n= 25), two lambs (n=30) or three lambs (n=10). All ewes and lambs were set-stocked as one mob on ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pastures under normal farming management. Nutrient status of the ewes was assessed at pre-lambing (day 1 of set-stocking), mid-lactation (day 63) and weaning (day 105) using live weight (LW), body condition score (BCS) and computed tomography (CT) measurements. Mobilisation of tissue reserves was determined by comparing the arithmetic means for LW, BCS and CT (fat, lean and bone tissue in the carcass) measurements at successive time intervals. The change in tissue reserves for ewes was correlated to the live weight gain (LWG) and weaning (WW) of lambs as a measure for assessing the lactation performance of ewes.

Mobilisation of body reserves by ewes during lactation was influenced by number of lambs reared. Ewes that did not rear lambs did not mobilise body reserves during lactation, while ewes that reared lambs showed marked declines in LW ($P = 0.024$), BCS ($P = 0.036$), carcass fat ($P = 0.019$) and net energy ($P = 0.03$), but not for lean and bone tissue. At the end of lactation (weaning), LW, BCS, carcass fat and NE declined by at least 19% of pre-lambing measurements, which became more profound with increasing number of lambs reared. Twin and triplet-bearing ewes mobilised more energy reserves than those with single lambs during early lactation, while all lamb-rearing ewes showed similar tissue mobilisation rates during the late lactation period. Although the LWG of lambs was low, lambs reared as singles grew 1.8 times faster than those reared as twins and triplets (P < 0.001). Lamb LWG and WW were poorly associated with changes in ewe body reserves during lactation. Moreover, ewes that mobilised more energy reserves tended to have lambs with a lower WW. Taken together, the findings of this study do not support the hypothesis that greater mobilisation of tissue reserves in ewes during lactation is associated with superior LWG and WW of lambs.

Keywords: Ewes, body condition score, computed tomography, lactation performance, lambs, live weight, mobilisation, tissue reserves, weaning weight.

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This thesis was conducted to determine whether ewes which mobilise more body reserved during lactation was associated with greater lamb weaning weights. The experiemtnal work for this study was carried out at the Lincoln University sheep unit, Canterbury, from September to December 2015 and report writing completed in subsequent months.

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List of abbreviations and symbols

ANOVA	Analysis of variance
BCS	Body condition score
Car. Fat	Carcass fat
CW	Carcass weight
Cm	Centimetre
cm^3	Centimetres cube
cm^2	Centimetres square
Δ	Change
R^2	Coefficient of determination
CT	Computed tomography
R	Correlation coefficient
CP	Crude protein
g	Gram
HU	Hounsfield units
h	Hour
kg	Kilograms
LSD	Least significant difference
<	Symbol for less than
LW	Live weight
LWG	Live weight gain
MJ	Megajoule
ME	Metabolisable energy
mid	Mid-lactation
ml	Millilitre
mm	Millimetre
min	Minutes
NE	Net energy
PPMCC	Pearson product-moment correlation
%	Percentage
pre	Pre-lambing
P	Probability
N	Abbreviation for sample size
*	Significant at 0.05
WW	Weaning weight

Chapter 1

Introduction

Lactation has been characterised as a three stage metabolic adaptation (*viz*: mamagenesis, lactogenesis and galactopoiesis) essential for the post-partum nourishment of offspring where mammalian species synthesise and secrete milk via the mammary gland (Schams, 1976). The capacity of mammals to produce and sustain milk secretion (galactopoiesis) has widely been accepted to be dependent on a series of well-orchestrated homeorhetic adaptations or metabolic changes prompting a reliable supply of glucose, amino acids and fatty acids to the mammary gland (Bauman, Lock, Baumgard, & Collier, 2004; Bell, 1995; Drackley, Overton, & Douglas, 2001; Hart, 1983; Joseph & Foot, 1990). A Major metabolic adaptation which occurs in mammals with the goal of satisfying lactogenesis and galactopoiesis includes an increase in the rate at which body tissues are catabolised relative to other physiological states (Bauman et al., 2004; Bell, 1995; Hart, 1983). This adaptation predominantly occur during periods of negative energy deficits (early lactation), where a lack of substrates and/or reduced efficiency in the use of nutrients supplied from the diet above maintenance (Cowan, Robinson, McDonald, & Smart, 1980; Geenty & Sykes, 1986) is compensated through the depletion of body tissues. In New Zealand, the occurrence of negative energy deficits during lactation in sheep is further exacerbated in dryland farming conditions and use of more desirable lands for higher return businesses, such as dairying (Bywater & Moot, 2011; Valentine & Kemp, 2007). Thus, the use of tissue reserves in sheep during lactation under such conditions can play an essential role in the performance of ewes.

Superior milk production from ewes occurs at very generous herbage allowances, feeding of energy dense feedstuffs (concentrates, cereals, grains etc.) or a combination of both. In most commercial systems under natural grazing conditions, generous herbage allowances are usually achieved by matching or synchronising the lactation period of ewes to spring, where pasture supply and quality is expected to be sufficient in meeting the physiological feed demands of stock (Bywater & Moot, 2011; Gray, 2007; Litherland & Lambert, 2007; Valentine & Kemp, 2007). However, even at generous herbage allowances and increased voluntary feed intake, lactating ewes have been reported to lose body condition as an adaptation to sustain milk secretion. It can therefore be presumed that ewes that mobilise more body reserves during lactation, under the aforementioned circumstances, are better able to buffer against stress imposed by physiological state (lactation) and nourish neonates post-natally.

Consequently, ewes that readily mobilise body reserves as an adaptation to sustain milk production may possess greater potential in achieving high levels of animal production in the form of greater live weight gains and weaning weight of lambs than ewes which seldom mobilise nutrient reserves. For this reason, metabolic adaptation in the form of the ease with which nutrient reserves are mobilised may serve as a good index for selecting and ensuring high levels of animal performance during lactation.

The past decades have given rise to the development of numerous techniques which have been shown to be very useful and reliable tools in non-destructive quantification of body composition in small ruminants. Conventional methods that can be used to predict body reserves with acceptable levels of accuracy based on established relationships with dissected tissues include live weight (LW) and body condition scoring (BCS) (Frutos, Mantecon, & Giráldez, 1997; Oregui, Gabiña, Vicente, Bravo, & Treacher, 1997; Russel, Doney, & Gunn, 1969; Van Burgel et al., 2011). Another method of assessing tissue reserves of small ruminants non-destructively involves the use of computed tomography (CT), which has been shown to be more accurate than BCS and LW, and very useful in quantifying individual tissue reserves (Lambe, Young, McLean, Conington, & Simm, 2003b; Young, Jay, & Jopson, 1999; Young, Nsoso, Logan, & Beatson, 1996). Therefore, measured changes with the above tools would be expected to provide a good assessment of the extent to which body deposits are depleted and/or replenished at different periods in a production cycle.

1.1 Aim and objective of the study

This study aims to determine whether tissue usage during lactation is a good measure for identifying ewes with superior phenotypic merits in terms of producing greater live weight gain and weaning weight of lambs. The main objective was to quantify the changes in tissue reserves in the carcass for ewes in a pastoral system and correlating these parameters to the gain in live weight and weaning weight of their respective lambs.

1.2 Hypothesis of study

It is hypothesised that ewes which mobilised more body reserves during lactation will be associated with superior live weight gains and weaning weights of lambs in a production season.

Chapter 2

Review of Literature

2.1 Changes in body reserves during lactation in sheep

The body consist of three main types of tissues, adipose, lean and bone. During times when nutrient demands exceed feed supply, such as lactation, these reserves have been shown to be depleted and subsequently replenished in varying proportions. Adipose has been documented as the most labile and reliable source of energy, in both proportionate and absolute terms, than lean and bone during periods of stress and under-nutrition induced by pregnancy and lactation (Cowan et al., 1980; Lambe et al., 2003a; Lambe et al.). Few studies have investigated the mobilisation of tissue reserves during lactation in sheep. The mobilisation of nutrient reserves in sheep has been explored using CT (Lambe et al., 2003a; Lambe et al.), BCS and LW (Borg, Notter, & Kott, 2009; Corner-Thomas et al., 2015; Gibb & Treacher, 1980; Mathias-Davis, Shackell, Greer, Bryant, & Everett-Hincks, 2013)

2.1.1 Changes in soft tissue reserves predicted using LW and BCS

The early lactation period of sheep can be characterised by a high demand for nutrients, above what it is usually supplied from the diet, despite marked increases in voluntary feed intake. Appraisal of ewe body composition using LW and/or BCS at different points during lactation could help create a clear picture with respect to the usage and replenishment of soft tissue (fat and lean) reserves. In support of this are the works of several authors (Borg et al., 2009; Corner-Thomas et al., 2015; Gibb & Treacherr, 1980; Mathias-Davis et al., 2013) who provided evidence explaining that changes in BCS and LW occur during lactation for different breeds of sheep, and these changes are consistent with theoretical descriptions on fat and lean tissue mobilisation patterns during lactation. Gibb and Treacher (1980) showed that Scottish half bred sheep lost LW and BCS during lactation, an effect which varied depending on initial fatness level. More specifically, fat ewes at lambing were observed to lose more LW (18.4 verses 15.5kg) and BCS (irrespective of stocking density) during lactation, but by weeks 14 to 16 post-lambing, LW and BCS measurements were not different between fatness level groups at lambing. In addition, Borg et al. (2009) showed on average ewes lost 5.37kg and gained 4.94kg LW during the early and late lactation period, respectively. In the same study, mean BCS reduced from 3.06 to 2.7 between the late gestation and lactation period. The findings of Gibb and Treacherr (1980) and Borg et al. (2009) are consistent with Lambe et al. (2003a) , where changes in muscle and fat determined from CT measurements were observed to be depleted and replenished during the early and late lactation interval, respectively (Table 2.1). Moreover, Borg et al. (2009) reported ewes which weaned twins lost more LW during early lactation (8.29 verses 3.41kg) and gained slightly more LW during the late lactation period (5 verses 4.33kg). The effects of the number of lambs reared on changes in BCS and LW were also examined by Mathias-Davis et al. (2013) and Corner-Thomas et al. (2015). Analogous to the conclusions made by Borg et al. (2009), these authors showed that ewes which reared twins lost more body condition and, in the case of Mathias-Davis et al. (2013) study, ewes rearing triplets lost more condition relative to those rearing singles and twins. More specifically, Corner-Thomas et al. (2015) showed ewes which reared twins were 5 and 6.2kg lighter than ewes that reared singleton lamb at day 18 and 79 (weaning) into lactation. Replacement of depleted reserves may also be influenced by age as younger ewes were determined to possess lower LW measurements at weaning than older sheep (Borg et al. (2009). In that regard, ewes in the age range of 2-6 years on average weighed 66.4 to 72.9 kg at weaning, which increased with the age of ewes. A possible explanation may be that younger sheep may still be in an active growing state and, consequently some of the nutrients supplied from the diet in times of attenuated demand for nutrients are predominantly partitioned towards the continuation of growth. Based on the findings of Gibb and Treacher (1980), Corner-Thomas et al. (2015), Mathias-Davis et al. (2013) and Borg et al. (2009), it can be asserted that changes in LW and BCS are apparent during lactation in sheep, the kinetics of which are influenced by body condition at lambing, number of lambs reared and the age of ewes.

2.1.2 Changes in adipose tissue

In describing the dynamics associated with the mobilisation of adipose tissue during lactation, it is first important to highlight the occurrence of two major groups of fat depots in mammals. These include: internal and carcass fat, whose degree of mobilisation during lactation has been identified to vary with a number of factors, including age, nutrition and number of lambs reared (Cowan et al., 1980; Lambe et al., 2003a). Carcass fat deposit is divided into subcutaneous and inter-muscular fat depots. Lambe et al. (2003a) observed in Scottish Blackface ewes that carcass and internal fat weight reduced from pre-lambing to mid-lactation (early lactation period) and was replenished from mid-lactation to weaning (Table 2.1). In addition, Lambe et al. (2003a) described the overall weight of carcass fat being greater than internal fat, but in proportionate terms internal fat was more severely depleted than carcass fat during the early stages of lactation. Similarly, Cowan et al. (1980) reported changes in the absolute weight of chemically determined fat in the carcass was greater than internal depots and *vice versa* for internal depots in proportionate terms. Cowan et al. (1980) showed that chemical fat in the carcass was reduced by 59% of initial levels 45 days into lactation for ewes which were given a diet which induced relatively low levels in tissue reserves during pregnancy, while internal fat depots for the same group of animals declined by 84%.

Late lactation (mid-lactation to weaning) is typically associated with the replenishment of the major fat depots, where internal and inter-muscular fat gain was reported to be greater compared with subcutaneous (table 2.1). Consequently, subcutaneous fat was considered as the most important fat reserve in fuelling milk production during periods of attenuated nutrient demands imposed by lactation.

Table 2.1: Changes in tissue weight (kg) between successive scanning events for Scottish Blackface ewes during the lactation period (Lambe et al., 2003a).

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2.1.3 Changes in lean tissue

The contribution of protein or lean tissue towards meeting the demands of lactation in sheep (Cowan et al., 1980; Lambe et al., 2003a; Lambe et al.) and goats (Eknæs, Kolstad, Volden, & Hove, 2006) has been investigated. Collectively, these studies suggest that lean tissue is less labile than total adipose tissue but more variable than bone. Lambe et al. (2003a) reported reductions in lean tissue for ewes during early lactation with an apparent effect of number of lambs reared (singles verses twins). Single-bearing ewes lost more lean tissue than ewes which reared twins regardless of age (table 2.2). This outcome was attributed to preferential feeding of ewes which reared two lambs. In contrast, Cowan et al. (1980)

reported lean tissue contribution towards milk production was identified to be of little quantitative significance. However, Cowan et al. (1980) did observe declines in lean tissue (26 grams day^{-1}) for ewes subjected to low energy diets during the early lactation period. This loss in protein was attributed to the mobilisation of large amounts of substrates from fat depots for galactopoiesis coupled with a lack of protein supplied from the diet. The high energy diets of Cowan et al. (1980) were not associated with the mobilisation of muscle, thus allowing for the suggestion that the contribution of lean tissue for galactopoiesis becomes profound only after fat reserves have fallen below a critical level. Furthermore, the animals in the Lambe et al. (2003a) experiment with higher mean reductions in the weights of fat depots had greater mobilisation of lean tissue (Table 2.2). This may have important implications for sheep reared under dry-land farming conditions, since in such situations lean tissue can play a critical role in the post-partum nourishment of lambs, particularly under circumstances where feed supplementation is not practiced.

During the late lactation period, muscle has been shown to be replenished at rates exceeding that of fat depots with an apparent effect of age (Lambe et al., 2003a; Lambe et al.). Lambe et al. (2003a) observed two year old ewes observed deposited similar amounts of lean tissue irrespective of number of lambs reared, whereas three year old ewes deposited more muscle when rearing single as opposed to twin lambs.

Although there is strong evidence supporting the use of proteinous tissue as a mechanism to sustain lactation in sheep (Geenty & Sykes, 1986; Lambe et al., 2003a; Lambe et al.), there is no literature describing a precise threshold in fat depots below which mobilisation of lean tissue becomes significant. However, based on the results of Lambe et al. (2003a), it may be speculated that during the early lactation period the correlation between the use of fat depots (mainly subcutaneous and internal fat) with muscle is positive. Intuitively, if this threshold exists, it would primarily occur subsequent to relatively large changes in fat depots or situations where fat depots nearly become exhausted as a metabolic adaptation to sustain milk production. If this is the case, the kinetics of muscle in lactating sheep could serve as an appropriate measure for assessing the severity of subcutaneous and internal fat mobilisation. The forgoing concept is consistent with the lactation adaptation where amino acids are used as a source of glucose when losses in fat tissues become unreliable (Cowan et al., 1980).

2.2 Technologies involved in the prediction of body composition

2.2.1 The use of live weight (LW)

Live weight (LW) is commonly used as a measure of assessing numerous production parameters that could help improve on-farm managerial decisions. Measurements of LW have been shown to be useful indicators of tissue reserve levels, reproductive performance, animal health and market specifications for livestock (Kenyon, Maloney, & Blache, 2014). The adoption of advanced automated weighing and data storage technologies has made the attainment of LW measurements simple, objective and less susceptible to human errors. Thus, the practicality of obtaining LW measurements in a farm setting is improved. Other factors, but uncontrollable to some extent, which have been identified to reduce the suitability of LW as a managerial tool for assessing body composition include the occurrence of *in vivo* effects associated with frame size, gut fill, fleece weight and fetus weight. Adult LW is a combination of frame size, body composition, internal organs, digesta and fetal development at the time of weighing (Borg et al., 2009). Therefore, if the sole purpose of LW is to predict body composition, overestimation would most likely be inexorable. For this reason, measurements associated with LW should be interpreted carefully and in some cases corrected for the aforementioned factors by fasting and multiple weighing of livestock.

2.2.2 Accuracy of LW

In spite of the limitations highlighted above, LW has been reported to be a good indicator of fat and muscle (Oregui et al., 1997; Russel et al., 1969; Sanson et al., 1993; Teixeira, Delfa, & Colomer-Rocher, 1989) and in some cases a better predictor than BCS (Frutos et al., 1997; Treacher & Filo, 1995). The variation in dissected tissues accounted for by changes in LW in the aforementioned studies was determined to be in the range of 57 to 90% for total and individual fat reserves. Collectively, the ranges reported in the literature provide evidence that LW is able to predict tissue reserves with moderate to high levels of accuracy.

2.2.3 The use of body condition score (BCS)

BSC is a system of describing the level of fat and muscle thickness at a particular time point within livestock. Although BCS scoring is subjective, it has been widely accepted as an international and reliable tool for appraising fat and muscle in an animal (Frutos et al., 1997; Oregui et al., 1997; Russel et al., 1969; Sanson et al., 1993; Teixeira et al., 1989; Van Burgel et al., 2011). Scoring is generally based on appraisal of tissue coverage by palpation of the backbone between the last rib and pelvis (lumbar region) according to a five-point scale described by Russel et al. (1969). The lumbar region is widely accepted as the area for practicing the technique as it is the main area of fat deposition and the last region to gain fat and first to lose it (Delfa, Teixeira, & Colomer-Rocher, 1989; Frutos et al., 1997).

The idea of appraising the body condition of sheep using a scoring system was pioneered by Jefferies in 1961 (SCARM, 1990), and later modified by Russel et al. (1969). BCS has its advantage over LW in that it requires no sophisticated weighing technology and measurements are independent of animal frame size. There may be situations where LW *per se* may not reflect an animal's body condition, and this has been attributed to differences in frame size between individuals and breeds of animals. In that matter, animals of large frame size have been associated with higher LW measurements but lower nutrient reserves than those of smaller frame sizes (Kenyon et al., 2014). Other factors that have been reported to contribute to skewed predictions in body reserves of ewes from LW measures include gut-fill, fleece growth and fetus development, which do not affect BCS.

2.2.4 Accuracy of BCS

It can be argued that BCS is preferable to LW in assessing the body composition of ewes. This assertion is supported in several studies involving sheep in different physiological states (Delfa et al., 1989; Oregui et al., 1997; Russel et al., 1969; Sanson et al., 1993; Teixeira et al., 1989; Van Burgel et al., 2011). In these, BCS was identified to account for more of the variation in viscera, organ, empty body, chemically determined and dissected fat and muscle than LW. The variation of total and individual fat and protein depots accounted for by BCS as deciphered from Van Burgel et al. (2011), Delfa et al. (1989), Sanson et al. (1993), Teixeira et al. (1989), Oregui et al. (1997) and Russel et al. (1969) range from 81 to 95%. In contrast, the notion that BCS is better at predicting body composition than LW was not in agreement with the findings of Frutos et al. (1997) and Treacher and Filo (1995). Sheep of Awassi and Churra pedigree, respectively, which have been described as breeds which deposit a large proportion of fat in other sites than the lumbar region. Therefore, under such circumstances, BCS would likely underestimate fat and lean tissue levels and, LW could be presumed to be a more reliable measure of overall body composition. Although this may be a valid reason to avoid the use of BCS in certain breeds of sheep, results from the Treacher and Filo (1995) and Frutos et al. (1997) studies have shown total, individual and carcass fat depots throughout the body of Churra and Awassi ewes to be well correlated with changes in BCS.

2.2.5 Repeatability of BCS

As with any form of subjective assessment, operator/human error and bias can lead to the occurrence of skewed predictions. Studies designed to evaluate bias and human error associated with the prediction of tissue reserves using BCS, have focused on generating inferences from multiple technicians using repeatability analysis (a measure of variation in measurements taken by an operator/s on the same experimental unit under similar experimental conditions). , Russel et al. (1969) determined the repeatability of BCS measurements in adult Scottish Blackface ewes to be in excess of 80 and 70% within and between several scorers over a period of 3 years, respectively. Likewise, Teixeira et al. (1989) reported repeatabilities of 90 and 80% within and between three technicians for Aragonesa ewes, respectively. Van Burgel et al. (2011) found high repeatability coefficients within and between all operators which assessed ewe body composition using the BCS technique. Taken together, these studies provide evidence that variation induced by bias and human error associated with BCS is minimal, and that a single highly experienced scorer is sufficient to produce reliable and/or accurate estimations of tissue reserves in sheep.

2.2.6 Relationship between changes in BCS and fat depots

Given the fairly high accuracy in predicting body composition of ewes, monitoring BCS would be expected to be a good indicator of the dynamics associated with tissue reserves. More specifically, any changes in BCS for an individual animal may be expected to be a good estimator of changes in fat levels and muscle dimensions. The relationship between BCS and fat levels in the body of sheep have been described by Russel et al. (1969), Delfa et al. (1989), Sanson et al. (1993), Treacher and Filo (1995) and SCARM (1990). A summary of the results reported in these studies is presented below in Table 1.

Table 2.2: Regression of fat in the body of sheep on BCS and associated protocol.

Physiological state and breed	Source	N	Slope	R^2	Association
Non-lactating ewes					
Scottish Blackface	Russel et al. (1969)	30	8.7	0.88	Empty body
Awassi^{+}	Treacher & Filo (1989)	84	0.87	0.66	Dissected
Awassi	Sanson et al. (1993)	14	3.3	0.90	Dissected
Awassi	Sanson et al. (1993)	14	3.7	0.95	Empty body
Rasa Aragonesa^{+}	Delfa et al. (1989)	52	0.76	0.94	Dissected
Rasa Aragonesa$^{+\alpha}$	Delfa et al. (1989)	52	0.9	0.88	Dissected
Rasa Aragonesa^{+Y}	Delfa et al. (1989)	52	0.57	0.81	Dissected
Rasa Aragonesa $^{+\varepsilon}$	Delfa et al. (1989)	52	0.59	0.92	Dissected
Lactating ewes					
Dorset	SCARM (1990)	20	10.1	0.64	Tritiated water
Sth Aust Merino	SCARM (1990)	10	5.8	0.36	Tritiated water
Saxo Merino	SCARM (1990)	10	7	0.35	Tritiated water
Corriedale	SCARM (1990)	10	7.4	0.46	Tritiated water

$^{+}$computed after $\log_{10}$ transformation, α omental fat, Y mesenteric fat, ε intermuscular fat

The low coefficient of determination reported by SCARM (1990), below the range previously mentioned in this review can be attributed to small sample sizes and the type of protocol used to quantify *in vivo* levels of fat (Table 2.2). Nonetheless, the relationships presented in Table 2.1 suggests that a unit change in BCS in lactating ewes can be in the range of 5.8 to 10% change in fat content, where the upper value can be associated with breeds of sheep exhibiting good maternal qualities and lower for those of other phenotypes, such as improved wool growth and carcass composition. By comparison, a unit change in BCS for non-lactating ewes may be expected to be in the range of 3.3 to 9% change in fat content. In addition, Table 2.2 provides evidence that within a particular breed, BCS can predict individual fat depots very accurately, and that the relationship varies between individual fat depots.

2.2.7 Relationship between changes in BCS and muscularity

Sanson et al. (1993), Delfa et al. (1989), Verbeek et al. (2012) and Van Burgel et al. (2011) examined the association of BCS with muscle depth and/or width. Sanson et al. (1993) indicate a unit in BCS in decreased in ovariectomised ewes was associated with 0.8 and 0.7% increase in dissected carcass and empty body protein, respectively, suggesting a negative correlation between BCS and muscle deposition in sheep. In contrast BCS and muscularity were positively correlated in ovary intact sheep in several studies (Delfa et al., 1989; Van Burgel et al., 2011; Verbeek et al., 2012). Taken together, Delfa et al. (1989), Verbeek et al. (2012) and Van Burgel et al. (2011) concluded that the *longissimus dosi* depth and eye muscle width and depth is highly correlated to BCS measurements, where ewes of low BCS were described to contain less muscle than ewes with superior BCS.

2.2.8 Relationship between changes in BCS and LW

BCS is a subjective instrument that can be used to evaluate body reserves in sheep. It can be argued that the suitability and reliability of the technique is influenced by the theoretical knowledge and practical experience of assessors. Intuitively, inaccurate calibration of nutrient reserves using the BCS technique rendered by a lack of experience and knowledge on the theoretical framework of the procedure could lead to skewed predictions. For this reason, the BCS technique is primarily performed by trained and experienced personnel, which has been identified to be a factor limiting the adoption of the technique in many commercial enterprises (Kenyon et al., 2014). On the other hand, contemporary LW measures can be described as an objective and more practical measure of quantifying tissue reserve levels in livestock, in that it requires little or no training and is less susceptible to human error and bias. Therefore, the use of LW or changes in LW as an estimator of BCS could serve as a simple and practical managerial tool for assessing body reserve levels in ewes at a particular time point. If possible, this rapid would facilitate quick and appropriate adjustments to inputs with the goal of prompting efficient on-farm management of livestock.

There is a broad range of evidence indicating a positive correlation between BCS and across various physiological states, age, parity and breeds of sheep (Caldeira & Portugal, 1991; Frutos et al., 1997; Jefferies, 1961; Oregui et al., 1997; Özder & Karadağ, 2008; Russel et al., 1969; Sanson et al., 1993; Sezenler, Özder, Yıldırır, Ceyhan, & Yüksel, 2011; Teixeira et al., 1989; Treacher & Filo, 1995; Van Burgel et al., 2011). Jefferies (1961) indicated a unit change in BCS in Merino and Corriedale ewes corresponded to a 7kg change in LW. Similarly, Russel et al. (1969), Sanson et al. (1993), Treacher and Filo (1995), Kenyon, Morel, and Morris (2004) and Van Burgel et al. (2011) using different breeds of sheep reported 10.56, 5.57, 5.06, 11.8, 7.3 and 9.2kg mean LW change per unit change in BCS, respectively. Furthermore, Özder and Karadağ (2008), Sezenler et al. (2011) and Oregui et al. (1997) provided evidence that the change in LW per unit change in BCS increased from pre- to post-lambing periods, indicating changes in LW per unit change in BCS is lower during mating and pregnancy than lactation and at weaning. More specifically, it was determined in Karacabey Merino ewes that a unit increase in BCS was equivalent to changes of 0.09, 0.08 and 0.11kg of mean LW at mating, lambing and weaning in the Özder and Karadağ (2008) study, whereas changes of 0.13, 0.12 and 0.15kg of mean LW for a mixed flock at the same periods were documented by Sezenler et al. (2011). Likewise, Oregui et al. (1997) with Latxa ewes reported greater changes in LW per unit change in BCS (5.3 to 6.3kg, respectively) from mating to post-lambing. These can be attributed to faster mobilisation of water and body reserves in the early lactation period and, heavier carcasses and lighter viscera in sheep losing weight compared with animals maintaining weight (Oregui et al. (1997). Consistent with the latter, Caldeira and Portugal (1991) showed in dry ewes that LW change per unit change in BCS was higher in animals losing or gaining weight relative to those on maintenance diets. Collectively, the relationship between LW and BCS is positively linear and varies between breeds, although Teixeira et al. (1989) described a curvilinear regression relationship in Rasa Aragonesa adult ewes as a unit change in BCS corresponded to 7, 10, 12 and 16kg change in LW from BCS one (1) to five (5), respectively.

Timing at which measurements were taken may influence the relationship between LW and BCS. Therein, Özder and Karadağ (2008), Sezenler et al. (2011) and Oregui et al. (1997) all reported differences in the accuracy with the time at which changes in BCS was associated with changes in LW measurements within various breeds of sheep. In the Özder and Karadağ (2008) study, R^2 values were estimated to be 0.39, 0.42 and 0.50 at mating, lambing and weaning, respectively. Likewise, Sezenler et al. (2011) observed R^2 estimates of 0.67, 0.53 and 0.57 at breeding, lambing and weaning, respectively. Özder and Karadağ (2008) indicated the accuracy of BCS in predicting changes in LW varies between pre- to post- lambing periods (0.59 and 0.50, respectively). Therefore, it can be presumed that at specific time points in the production cycle for an individual animal or breed, LW *per se* may be a more reliable estimator of body composition than BCS and *vice versa* at other intervals. There is currently no literature comparing the accuracy of the two protocols in predicting body condition (BCS and LW) at different time points during the lactation period in sheep.

As ruminants get older the correlation between LW and BCS becomes stronger, and variability in LW brought about by factors other than body tissues become less profound. Özder and Karadağ (2008) showed regression coefficients for LW on BCS were greatest in older (6 to 7) ewes at mating, lambing and weaning. In cattle, Berry, Macdonald, Penno, and Roche (2006) and Berry, Buckley, and Dillon (2011) showed that the changes in LW per unit change in BCS increased with parity, thus suggesting that the BCS for older, multiparous cows were more responsive to changes in body composition. Variability in the relationship between LW and BCS brought about by differences between breeds may best be described through variances in the distribution of fat within animals, frame size and weight (Frutos et al., 1997). As a result, a relationship developed with a particular breed cannot be applied with confidence to another.

2.2.9 Computer tomography

The use of CT to predict *in vivo* levels of fat, muscle and bone in different regions of the body for ewes has been investigated by (Lambe et al.; Lambe et al., 2003b; Young et al., 1999; Young et al., 1996). Two major approaches have been utilised to predict body composition of ewes. The first involves the Cavalieri method in which 15 to 20 evenly spaced X-ray cross-sectional images along the long axis of an organism is manufactured wherein the first slice position is chosen at random in the neck region (Young et al., 1996). The second approach involves the reference method that uses information from X-ray cross-sectional images at fixed anatomical sites (usually seven) along the body of an organism (Lambe et al., 2003b; Young et al., 1999; Young et al., 1996). The Cavalieri scan procedure attenuates errors associated with animal positioning as it has been shown to provide a direct measurement of body tissues in a manner that is independent of body shape during scanning (Szabo et al., 1999).

2.2.10 Accuracy of computed tomography (CT)

Comparison of CT to dissected tissue measurements in sheep has justified the use of CT technology as a good predictor of tissue reserves in ewes (Young, Garden, & Knopp, 1987) and lambs (Jones, Lewis, Young, & Wolf, 2002; Navajas et al., 2007). Young et al. (1987) reported correlation coefficients between CT and dissected measures equivalent to 0.997, 0.985 and 0.992 for fat, muscle and bone, respectively. In addition, Jones et al. (2002) showed correlations between CT and dissected measurements of muscularity in the range of 0.32-0.44, 0.55 and 0.49-0.69 in the *M. lingissmus thoracis et lumborum*, whole carcass and hind leg, respectively. Similarly, Navajas et al. (2007) showed using a novel muscle index that correlations between CT and dissection measures of muscularity in the hind leg and lumbar region was equal to 0.89 and 0.55, respectively.

CT scanning provides a non-destructive method of accurately predicting body composition directly. Lambe et al. (2003b), reported total carcass fat, carcass muscle, internal fat, inter-muscular fat and subcutaneous fat to be predicted with a high accuracy (98.6, 81.4, 79.6, 95.1 and 96.1%), while accuracies associated with bone were moderate (R^2 = 56.1%) in Scottish Blackface ewes. Moreover, repeatability was determined to be very high for CT measurements used to predict fat and muscle (0.82 – 0.99) but generally lower for those used to predict bone (0.19 – 0.86). The lower coefficient of determination (R^2) and repeatability obtained for CT bone measurements in the study by Lambe et al. (2003b) was attributed to errors associated with the precise registration of scans. In comparison, bones are more complex in shape and structure than fat and muscle and consequently have been shown to suffer from considerable variability rendered by animal posture and movement during the scanning process (Lambe et al., 2003b; Young et al., 1999). Similarly, Young et al. (1999) reported R^2 values in the range of 85-95%, 80-94% and 13-48% for fat, muscle and bone tissues respectively using four reference scans. In the same study, repeatability associated with a single scorer for fat, muscle and bone was determined to be in excess of 97%. Young et al. (1996) showed the reference scan technique can predict *in vivo* body tissue levels very accurately (R^2 = 72-84%, 79-78% and 62-66% for fat, muscle and bone, respectively) and, incorporating LW into the prediction model further increased its accuracy (Young et al., 1996). Taken together, the findings of Lambe et al. (2003b), Young et al. (1999) and Young et al. (1996) suggest CT scanning via the reference scanning procedure is moderately to highly accurate in predicting body reserves for ewes.

2.3 Relationship between the mobilisation of tissue reserves by ewes and lamb live weight (LW) at weaning

Changes in individual tissue reserves may influence the lactation performance of ewes. From the perspective of tissue mobilisation during lactation, the term 'lactation performance' may refer to the effects of body tissue usage on milk yield, milk composition, subsequent survival and growth rates of lambs and/or a combination of all parameters. As shown in several studies (Borg et al., 2009; Corner-Thomas et al., 2015; Gibb & Treacher, 1980; Kenyon et al., 2009; Mathias-Davis et al., 2013; Mathias-Davis, Shackell, Greer, & Everett-Hincks, 2011; Sejian, Maurya, Naqvi, Kumar, & Joshi, 2010; Verbeek et al., 2012), the growth rate of lambs is a common and simple measure for assessing phenotypic merits associated with ewe performance during lactation. Faster growing lambs from individuals, lines and/or breeds of ewes achieve target weights faster and can be weaned earlier in order to take advantage of premium prices of meat and reduce grazing pressure before pasture supply and quality becomes highly restricted by climatic variability in the summer.

The mobilisation of nutrient reserves from ewes during lactation has been reported to have either no effect (Gibb & Treacher, 1980; Litherland, Lambert, & McLaren, 1999) or a positive effect (Borg et al., 2009; Corner-Thomas et al., 2015; Gibb & Treacher, 1980; Kenyon et al., 2009; Mathias-Davis et al., 2013; Mathias-Davis et al., 2011; Scobie, Connell, Noble, & Greer, 2016; Sejian et al., 2010; Verbeek et al., 2012) on lamb growth rates using BCS, LW or both protocols. This inconsistency in the literature, according to Kenyon et al. (2014), may be attributable to differences induced by the timing of BCS and LW measurements, level of BCS and LW being compared, feeding regime before and throughout lactation and number of lambs reared per ewe. Other probable factors that may contribute to variation between the above studies include breed effects, birth weight of lambs and lamb survival to weaning.

For studies in which the mobilisation of nutrient reserves was determined to have an effect on lamb weaning weights, lambs which exhibited superior weights were consistently associated with 'elastic ewes', which readily lost body condition during the early lactation period and regained condition during the late lactation interval. Furthermore, analysis of results from Kenyon et al. (2009), Sejian et al. (2010), Mathias-Davis et al. (2013), Mathias-Davis et al. (2011), Borg et al. (2009), Gibb and Treacher (1980), Verbeek et al. (2012) and Corner-Thomas et al. (2015) showed the association between lamb weaning LW and tissue mobilisation is influenced by the level of body reserves during the late gestation period. In addressing this factor, results across seven (7) studies have proven to be equivocal. While Verbeek et al. (2012), Sejian et al. (2010), Corner-Thomas et al. (2015), Kenyon et al. (2009), Mathias-Davis et al. (2013) and Gibb and Treacher (1980) all concluded that superior body condition (measured either through BCS and/or LW) during the pre-lambing interval was associated with higher weaning LW of lambs, Mathias-Davis et al. (2011) showed no effects. Also, it is important to emphasise, based on findings from Corner-Thomas et al. (2015) and Sejian et al. (2010) that increases in LW gain of lambs can occur within a range of pre-lambing BCS for ewes. For example, Corner-Thomas et al. (2015) reported the weaning weights of lambs born to dams with a late pregnancy BCS of 2.5 and 3 units were 1.4 kg greater than those dams with 2 units. Likewise, Sejian et al. (2010) reported lamb growth from ewes which were maintained at 3 to 3.5 BCS performed better than those at lower and similar to higher BCS groups. On average, ewes maintained at 3 to 3.5 BCS units produced lambs that were 2.3 kg heavier than ewe with 2.5 units at weaning.

2.3.1 Implications of the relationship between changes in tissue reserves for ewes with the live weight gain and weaning weight for lambs

One of the important drivers of profit in the commercial production of sheep is the number and total LW of lambs weaned per hectare. In this regard, there is evidence indicating that lamb survival and weaning weight are affected by the mobilisation of nutrient reserves by ewes during lactation (Borg et al., 2009; Corner-Thomas et al., 2015; Gibb & Treacher, 1980; Kenyon et al., 2009; Mathias-Davis et al., 2013;

Mathias-Davis et al., 2011; Scobie et al., 2016; Sejian et al., 2010; Verbeek et al., 2012). In general, ewes with superior body condition during the late pregnancy period and poorer condition at weaning were associated with higher lamb survival and total LW weaned per ewe.

Given the relatively high accuracy of LW, BCS and CT in predicting tissue reserves in most breeds of sheep, an association with LWG and WW of lambs could help in identifying ewes willing to mobilise tissue reserves and have greater lactation performance. Selecting and breeding of ewes which readily mobilise nutrient reserves during lactation could aid in the production of breeds and lines that are likely to produce high lamb survival to weaning and weaning LW of lambs. From a physiological point of view, changes in LW, BCS and CT measurements for fat and muscle during lactation would be expected to indicate the extent at which body reserves are depleted and replenished as deficits in substrates supplied from the diet are compensated through the mobilisation of fat and lean reserves. This therefore would make it relatively easy to identify such ewes at specific points in their production cycle. Sheep with less variability in tissue mobilization may be expected to produce less milk relative to those with greater reductions during the early lactation interval. This could impact on the weight gain, lamb weaning weight and farm profitability.

2.4 Tissue mobilisation and milk production

Milk yield and composition is affected by the degree of tissue mobilisation. Cowan et al. (1980) showed lactating ewes that utilised greater levels of soft tissue (fat and lean reserves) produced lower yields of milk, milk fat and milk protein relative to sheep that utilised less tissue reserves during lactation (Table 2.3). However, in proportionate terms, in the same study milk fat, fractions were slightly superior for animals that were exposed to greater levels of soft tissue mobilisation irrespective of feeding level during late pregnancy (Table 2.3). In addition, Cowan et al. (1980) indicated subsequent weight gain (live weight) for lambs suckling mothers with higher levels of tissue reserves were slower than those exposed to lower levels. Interestingly, a kilogram (kg) of live weight gain for lambs was associated with milk intakes equivalent to 5.7 and 6.7kg/lamb from ewes which mobilise less as opposed to more tissue reserves during lactation, respectively. Cowan et al. (1980) extrapolated that despite the fact that less milk was produced from ewes with greater levels of tissue depletion, it may require less milk from these ewes to produce a unit increase in live weight for lambs. This was attributed to a superior milk composition *per se* compared with ewes subjected to lower levels of soft tissue depletion. In support, Geenty and Sykes (1986) reported the depletion of soft tissues to be associated with lower absolute levels of milk yield, milk protein and lactose, but not milk fat; with milk fat content increasing as fat mobilisation increased. Furthermore, the authors reported a linear increase in the utilisation of ME for milk production with lean tissue mobilisation. Few studies have investigated the role of specific tissue mobilisation to lactation performance of ewes in the form of milk yield and composition.

Table 2.3: Effect of feeding level in pregnancy and diet in lactation on yield and composition of milk in the first 6 weeks of lactation (Cowan et al., 1980).

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2.5 Summary

The literature suggests that LW, BCS and CT measures are very useful and reliable tools in predicting changes in body composition in sheep non-destructively. The consensus from previous research indicate that body tissue reserves are depleted during early lactation and replenished during the late lactation interval. In addition, the mobilisation of tissue reserves across several studies was influenced by the number of lambs reared, age and initial tissue reserve level during the lactation period. The growth rate and weaning weight of lambs is an important driver of profit for commercial production sheep. Ewes that wean heavier lambs would facilitate quicker target weights at slaughter for lambs and could be favoured in breeding and selection decisions. Many studies suggest that ewes which mobilise more tissue reserves during lactation are associated with greater lamb weaning weights. One criterion that can be used to select for ewes which display good performance during lactation involve the ease at which they catabolise body tissue reserves.,

As a result, this study will test the hypothesis explaining that lactating ewes which mobilise more tissue reserves in the carcass are associated with greater LW gain and weaning weight of lambs during a production season. In addition, the extent at which individual tissue reserves (fat, lean and bone) are mobilised by ewes will be examined according to the number of lambs reared.

Chapter 3

Materials and Methods

3.1 Experimental Design

The change in carcass tissue reserves of ewes in relation to weight of lamb produced was assessed. Seventy-four mixed breed (predominantly Coopworth) ewes with a mean LW of 76.5 ± 7.3 and BCS 3.5 ± 0.5 were assessed for changes in body tissue reserves during one lactation period. Prior to lambing ewes were set-stocked as one mob on ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pastures under normal faming management (day 1). At lambing, lambs were tagged at birth with an electronic eartag (Allflex, New Zealand) with the date of birth and dam recorded. Mean lambing date was at day 21 post set-stocking. All ewes were exposed to the same diet and grazing conditions throughout the trail. At regular intervals (described below) the nutrient status of the ewes in relation to the weight of lamb produced was assessed using a combination of live weight (LW), body condition score (BCS) and computed tomography (CT). The number of ewes that reared 0, 1, 2 and 3 lambs was 9, 25, 30 and 10, respectively. Only ewes which provided data at pre-lambing (day 1) mid-lactation (day 63) and weaning (day 105) were included in the data set of this study. There were no mortalities of lambs from the selected ewes which reared lambs throughout the trial. Ewes labelled as zero (0) bearing ewes were defined as those animals which did not rear a lamb from tailing in the trial. All animals remained set-stocked until weaning at day 105. All procedures were carried out with approval from and under the authorisation of the Lincoln University Animal Ethics Committee, application number LU647.

3.2 Live weight (LW) and body condition score (BCS) measurement of ewes

Live weight (LW) and body condition score (BCS) of all ewes were assessed at set stocking (day 1) then four weeks from mean lambing date (day 49) and every two weeks thereafter until weaning on day 105. Live weight was recorded using a prattley swing-gate autodrafter (Prattley Industries, Temuka, New Zealand) and a Tru-test XR3000 head unit (Tru-test Ltd, Auckland, New Zealand) with a sensitivity of 0.2kg. BCS was assessed following palpation of the lumbar region by a single experienced assessor. Scores were given using a scale of 1 to 5, with 1 being emaciated and 5 obese. BCS was recorded to the nearest 0.5 unit as described by Russel et al. (1969) technique following palpation of the lumbar vertebrae.

3.3 Live weight gain (LWG) of lambs

The LW of lambs was recorded at mean of 4-weeks-of-age (day 49; tailing), mid-lactation (day 63) and weaning (day 105).

3.4 Computed tomography (CT) scanning of ewes

Carcass composition of the ewes was assessed using computed tomography (CT) at three time points, viz, pre lambing (day 1), mid lactation (day 63) and weaning (day 105). At each time ewes were fasted for 6h prior to scanning. For the mid-lactation event lambs remained at foot with ewes and lambs separated for a maximum of 2h immediately prior to CT scanning, being reunited immediately after scanning. Ewes were sedated with 0.5ml Acezine delivered intramuscularly 30min prior to scanning. Immediately prior to scanning ewes were restrained in a prone position on their backs with legs extended during scanning. CT images for carcass composition were obtained from the Gigot, Femur, Hip, 5th lumbar vertebrae, 2nd lumbar vertebrae, 8th thoracic vertebrae and 6th thoracic vertebrae as described by lambe et al. (2003b) and Young et al. (1999).

3.4.1 Partitioning of fat, muscle and bone tissues in the carcass

The cross-sectional images obtained from CT scanning revealed differences in colour densities (Hounsfield units) of individual tissue depots for each animal. Each cross-sectional image was processed in Star 3.9 software to separate the internal organs from the carcass. The differences in colour densities was used by Star 3.9 to measure the area (cm^2) and depth (cm) for fat, muscle and bone in each sectional slice, with densities in the range of -100 to -50, +10 to +40 and +300 HU and above were defined as fat, muscle and bone tissue, respectively. The distances (mm) between cross-sectional images, area and depth acquired from image analysis in Star 3.9 was entered into a formatted spread sheet in Microsoft Excel, where the volume (cm^3) and weight (kg) of individual tissue depots in the carcass of each animal was calculated. The volume and density measures obtained from image analysis in Star 3.9 for each animal was converted to mass using the following formula: Mass (kg) = Volume (cm^3) × Density (HU). Carcass weight (kg) was calculated as the sum of the total weight for fat, muscle and bone in the carcass for individual animals.

3.5 Data analysis and calculations

3.5.1 Adjusted pre-lambing LW

Due to the presence of the conceptus recorded LW's pre-lambing were adjusted to obtain a conceptus-free estimated live weight. Utilising the CT data for carcass weight for time periods when ewes were not pregnant (mid lactation and weaning), live weight was regressed with carcass weight (Figure 3.1). The line of best fit was the equation Y= $-0.052x^2 + 4.838x - 21.702$ (R^2=0.86) where Y= live weight and x = carcass weight. Carcass weight estimates from the CT scanning at pre-lambing (day 1) were then used to calculate a conceptus-free live weight at this time. The mean adjusted pre-lambing LW for ewes which reared 0, 1, 2 and 3 lambs was equivalent to 79.25 ± 8.57, 78.13 ± 7.9, 74.51 ± 6.31 and 76.15 ± 6.79 kg, respectively. For the remaining time points actual recorded live weights were used.

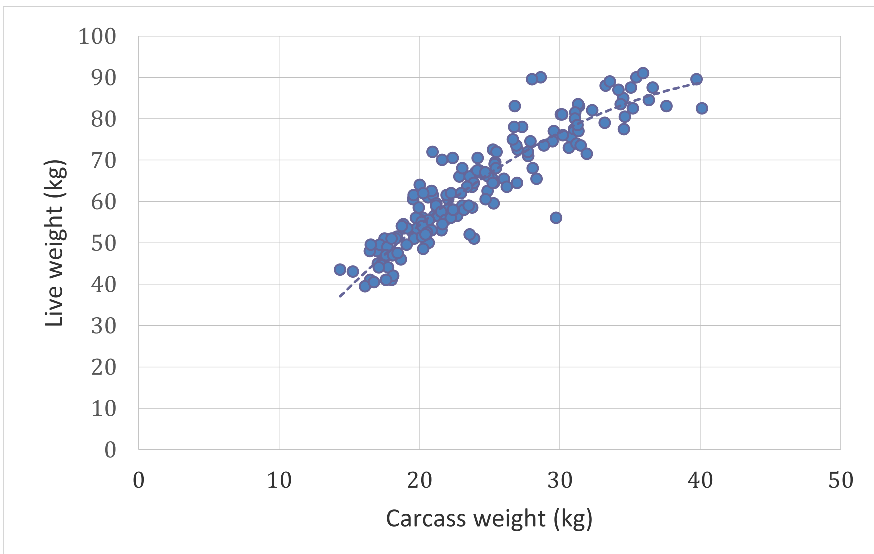

Figure 3.1: Regression describing the relationship between carcass weight and live weight for non-pregnant ewes in the study population. The regression equation describing the relationship above is as follows: y = $-0.052x^2 + 4.838x - 21.702$ (R^2 = 0.86).

3.5.2 Change in nutrient status

Net energy content of the carcass was estimated using CT data on carcass bone, lean and adipose assuming each tissue contained 10, 6 and 38 megajoules per kg, respectively, (Blaxter & Rook, 1953). Tissue mobilisation was assessed using the changes in LW, BCS, carcass lean, carcass fat, carcass bone, carcass weight and net energy of the carcass between periods where carcass composition was assessed. This gave three periods of interest, between pre-lambing and mid-lactation (early lactation); between mid-lactation ad weaning (late lactation) and during the entire lactation period (pre-lambing to weaning). For each of these time periods change in tissue reserves for ewes was correlated with the live weight change of the lambs reared in order to examine the lactation performance of ewes. In addition, the relationship between changes in CT with LW and BCS, and LW with BCS was examined to facilitate inferences on the accuracy of BCS and LW in determining changes in fat and lean reserves in sheep.

3.5.3 Covariate structure

Before statistical analysis, data sets for LW, BCS and CT measurements were divided into four groups based on the number of lambs reared during lactation. As a result, the effect of litter size during lactation was investigated as a covariate for each research objective. This was done in order to minimise skewed results in predicting body reserve level in the carcass of ewes at periods where tissue reserves were assessed.

3.5.4 Statistical analysis

Data were analysed using a combination of statistical software; viz., Minitab 16 (Minitab Inc, U.S.A), Genstat 16th edition (Lawes Agricultural Trust, Rothamstead, U.K.) and Microsoft excel 2013 (Microsoft Corporation, U.S.A). Change in ewe measurements (LW, BCS, carcass fat, carcass bone, carcass muscle and NE) during lactation was identified using the interaction component in an accumulated analysis of variance (ANOVA). This model utilised the interaction between litter size and time to assess change in ewe measurements. The least significant difference (LSD) Tukey post hoc test was used to determine which arithmetic means for individual ewe measures was different with time by the number of lambs reared. One-way ANOVA with Fisher's LSD post hoc test was used to analyse the effect of number of lambs reared by ewes on the mean changes in ewe measurements, live weight gain and weaning weight for lambs in the trial. To investigate whether a relationship existed between changes in ewe measurements with live weight gain and weaning weight of lambs, correlation coefficients calculated from linear regression was compared to a critical correlation value obtained using the Pearson product-moment correlation coefficient (PPMCC) protocol. Relationships whose calculated coefficients was greater than those obtained from PPMCC was deemed significant. Linear regression was used to describe the relationship between LW with BCS and, LW and BCS with CT measures. The effects of variables were defined significant at P values less than 5% ($P < 0.05$).

Chapter 4

Results

4.1 Change in tissue reserves for ewes

4.1.1 Changes in live weight (LW) and body condition score (BCS) measurements

The mean live weight (LW) and body condition (BCS) measurements of ewes separated by the number of lambs reared at pre-lambing, mid-lactation and weaning are shown in Figure 4.1. Pre-lambing LW measurements were corrected for fetal development as described in chapter 3.5. Overall, there were interactions between time and number of lambs reared for both LW (P = 0.024) and BCS (P = 0.036). Ewes which did not rear lambs had similar mean LW and BCS measurements at all time intervals. There were no differences in LW and BCS for ewes which reared one lamb at the end of early-lactation, but significant reductions in LW and BCS were observed at the end of the late-lactation interval. Reductions in LW and BCS during late lactation was 271 g per day and 0.5 units for single-bearing ewes, respectively. However, twin and triplet-bearing ewes had lower LW and BCS at mid-lactation and weaning. The total loss in LW and for twin and triplet-bearing ewes during lactation averaged 216 and 226 g per day, respectively. Likewise, BCS reduced by 1.2 and 1.4 units for twins and triplets during lactation, respectively.

4.1.2 Change in computed tomography (CT) measurements

The mean carcass weights predicted from computed tomography (CT) for individual tissue depots at pre-lambing, mid-lactation and weaning are given in Figure 4.2. Overall, there was an interaction between the number of lambs reared and time on total fat weight in the carcass (P = 0.019) but not bone (P = 0.554), lean (P = 0.877) and total carcass weights (P = 0.166). There were no differences in carcass fat weight for ewes which did not rear lambs at each period. Ewes which reared single, twins and triplets had lower mean carcass fat weights at mid-lactation and weaning. Mobilisation of carcass fat for single, twin and triplet-bearing ewes during early lactation was 45, 78 and 81 g per day, respectively. Fat in the carcass on average was reduced by 62 g per day only for twin and triplet-bearing ewes during the late lactation interval.

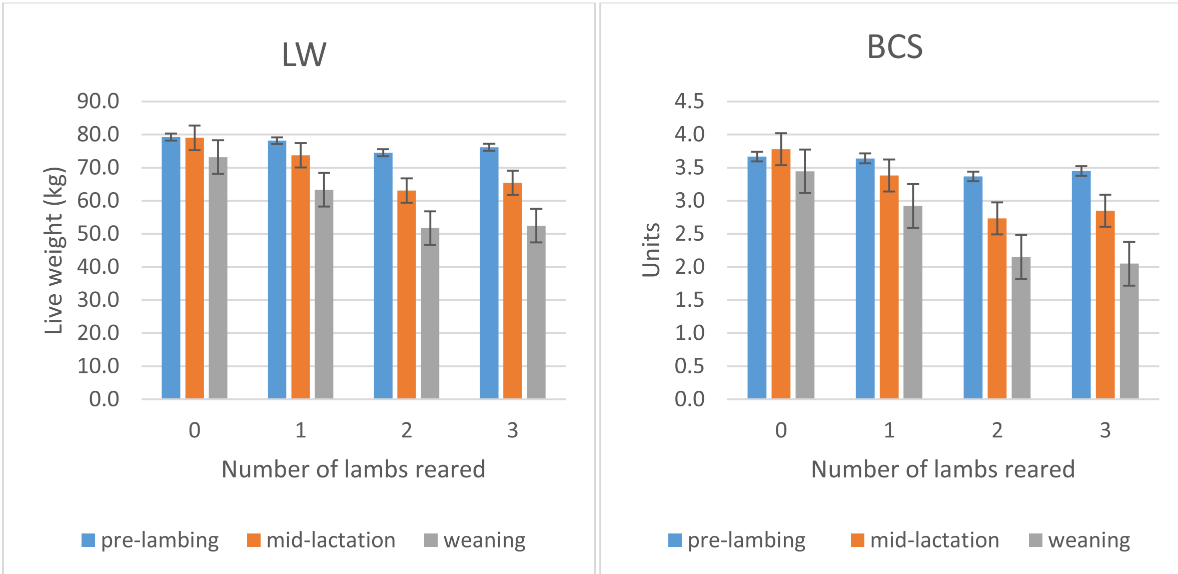

Figure 4.1: Mean LW (kg) and BCS (units) measurements obtained for ewes at three time points during the lactation period by number of lambs reared. The pre-lambing LW for ewes were corrected for fetal growth and development.

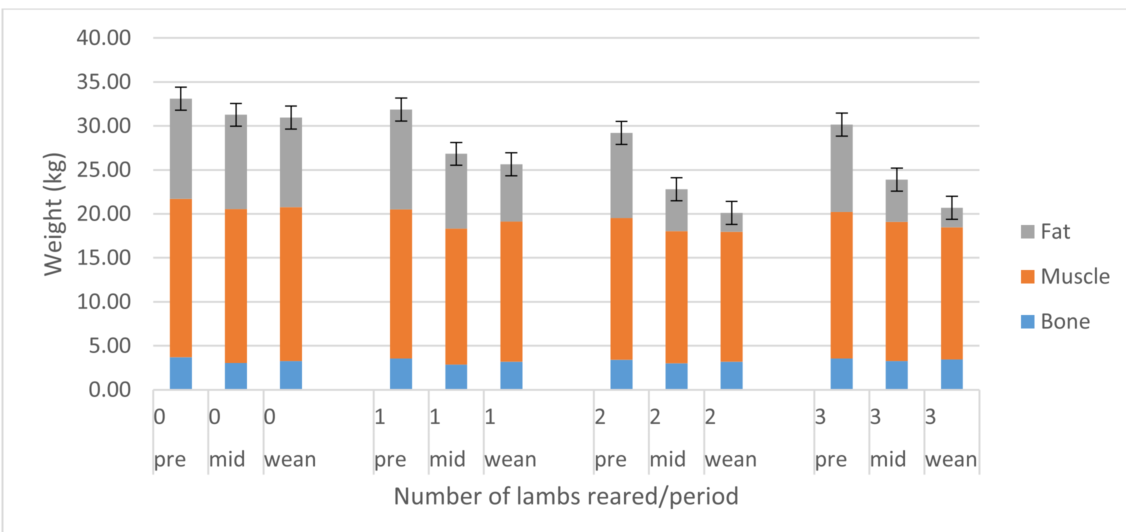

Figure 4.2: Mean CT weights (kg) for total fat, lean and bone in the carcass of ewes at three time points during the lactation period by the number of lambs reared: Pre (pre-lambing); mid (mid-lactation); wean (weaning).

4.1.3 Changes in net energy

The estimated net energy (NE) in the carcass of ewes at pre-lambing, mid-lactation and weaning are given in Figure 4.3. There was an interaction between time and number of lambs reared (P = 0.03) for NE stored in the body of ewes. Net energy measurements were similar between periods for ewes which did not rear lambs. Net energy stored in the carcass for single-bearing mothers was reduced by 22% at the end of early lactation, but was similar between the mid-lactation and weaning interval. However, twins and triplets had lower NE measurements at mid-lactation and weaning. On average, ewes which reared twins and triplets lost 40% of NE stored in the carcass at mid-lactation, whereas reductions in NE of 33% were observed at the end of the late lactation period.

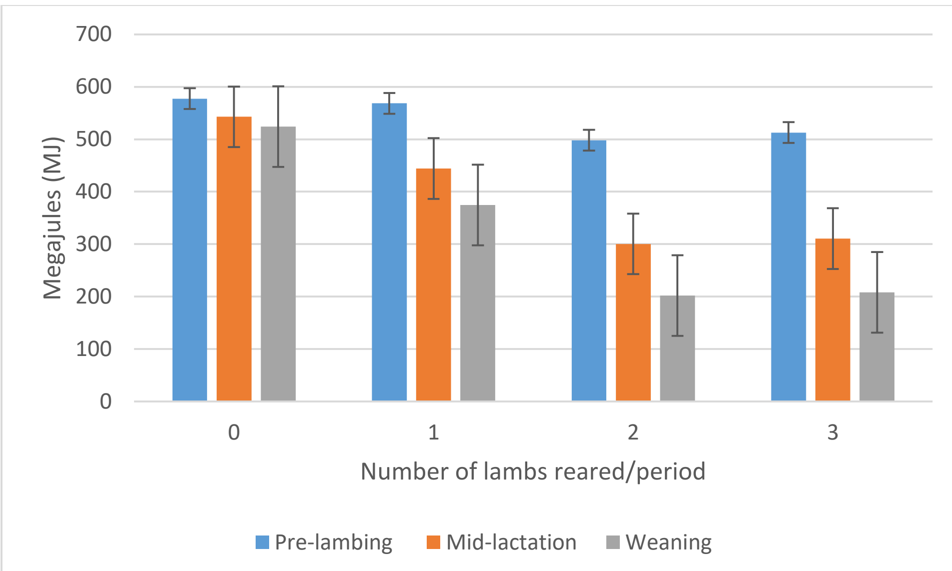

Figure 4.3: Mean estimate for net energy (MJ) in the carcass of ewes at three time points during lactation by the number of lambs reared.

4.2 Effect of number of lambs reared on mean changes in individual ewe traits

Overall, there was an effect of number of lambs reared on the changes observed for LW, BCS, carcass fat and NE at each time interval. There were differences in the mean changes for ewe traits between ewes which did not rear lambs, ewes which reared lambs and within the group of ewes which reared lambs, as described below. The mean pre-lambing and changes in ewe traits at three periods during lactation by the number of lambs reared are given in Table 4.1. Overall, pre-lambing ewe measurements were similar irrespective of the number of lambs reared by ewes. The effect of number of lambs reared on the changes in lean, bone and carcass weight (CW) were not examined as they did not change across time (Figure 4.2).

Table 4. 1: Mean initial (pre-lambing) measurements for live weight (LW; kg ± s.e), body condition score (BCS; units ± s.e), carcass fat (Car. fat; kg ± s.e) and net energy (NE ± s.e) of ewes and their mean changes (Δ) between three successive periods during lactation by number of lambs reared. The pre-lambing LW measurements were adjusted for fetal growth and development (Concepta-free live weight; Cf LW).

Number of lambs	0	1	2	3	
N	9	25	30	10	P-value
Ewe trait			Pre-lambing		
Cf LW	79.25 ± 8.57^{a}	78.13 ± 7.9^{a}	74.51 ± 6.31^{a}	76.15 ± 6.79^{a}	0.100
BCS	3.67 ± 0.50^{a}	3.64 ± 0.68^{a}	3.37 ± 0.43^{a}	3.45 ± 0.28^{a}	0.071
Car. fat	11.38 ± 5.41^{a}	11.35 ± 3.76^{a}	9.66 ± 3.01^{a}	9.93 ± 2.64^{a}	0.291
NE	577 ± 215^{a}	569 ± 152^{a}	498 ± 116^{a}	513 ± 108^{a}	0.228
Ewe trait			Early lactation		
ΔLW	-0.25 ± 6.63^{a}	-4.39 ± 6.85^{a}	-11.39 ± 8.12^{b}	-10.75 ± 9.19^{b}	0.054
ΔBCS	0.11 ± 0.42^{a}	-0.26 ± 0.54^{ab}	-0.63 ± 0.43b^{c}	-0.60 ± 0.57^{bc}	0.001
ΔCar. fat	-0.66 ± 3.12^{a}	-2.84 ± 2.21^{b}	-4.93 ± 2.21^{c}	-5.11 ± 2.21^{c}	0.001
ΔNE	-35 ± 125^{a}	-124 ± 90^{b}	-198 ± 89^{c}	-202 ± 96^{c}	0.001
Ewe trait			Late lactation		
ΔLW	-5.83 ± 4.56^{a}	-10.44 ± 4.57^{b}	-11.37 ± 4.94^{b}	-12.95 ± 5.16^{b}	0.011
ΔBCS	-0.33 ± 0.35^{a}	-0.46 ± 0.54^{ab}	-0.58 ± 0.44^{ab}	-0.80 ± 0.48^{b}	0.136
ΔCar. fat	-0.55 ± 1.87^{a}	-2.00 ± 1.53^{b}	-2.60 ± 1.06^{b}	-2.62 ± 1.44^{b}	0.002
ΔNE	-19 ± 75^{a}	-70 ± 63.29^{b}	-99 ± 39^{b}	-102 ± 59^{b}	0.002
Ewe trait			Pre-lambing to weaning		
ΔLW	-6.08 ± 9.54^{a}	-14.83 ± 9.43^{b}	-22.76 ± 6.83^{c}	-23.7 ± 7.92^{c}	0.001
ΔBCS	-0.22 ± 0.51^{a}	-0.72 ± 0.60^{b}	-1.22 ± 0.58^{c}	-1.40 ± 0.57^{c}	0.001
ΔCar. fat	-1.21 ± 4.17^{a}	-4.84 ± 3.40^{b}	-7.52 ± 2.74^{c}	-7.73 ± 2.14^{c}	0.001
ΔNE	-53 ± 167^{a}	-194 ± 135^{b}	-296 ± 106^{c}	-304 ± 92^{c}	0.001

^{a,b,c} Values within row with different superscripts are different at the $P < 0.05$ level of significance.

4.2.1 Changes in ewe traits during the pre-lambing to weaning period

Throughout lactation (pre-lambing to weaning), ewes which reared lambs lost more LW, BCS and carcass fat and NE than ewes with no lambs; viz., 8.75 to 17.62kg, 0.5 to 1.15 units, 3.63 to 6.52kg and 140 to 251 MJ more for LW, BCS, carcass fat and NE, respectively. Mean change in all ewe traits were lower for single than twin and triplet bearing mothers, with twin and triplet-bearing ewes showing similar changes

4.2.2 Changes in ewe traits during the early lactation period

The mean change in ewe traits relative to the number of lambs reared during the early lactation period are given in Table 4.1. Overall, animals which reared lambs had greater reductions in ewe traits than ewes which had no lambs, except for single bearing mothers for LW and BCS measures. Twin and triplet bearing ewes on average lost 11.14 and 10.5kg and 0.52 and 0.49 units more in LW and BCS than ewes which reared no lambs, respectively. Animals which reared lambs (single, twins and triplets) lost at least three times the amount of carcass fat and NE in comparison with mothers that did not rear lambs. Twin and triplet bearing ewes on average had greater reductions in LW (7 and 6.36kg, respectively), carcass fat (2.09 and 2.27kg, respectively) and NE (74 and 78 MJ, respectively) than ewes which reared one lamb. Conversely, the changes in BCS for triplet bearing mothers were similar to ewes which reared one lamb, while twin bearing mothers on average lost 0.37 units more than single mothers.

4.2.3 Changes in ewe traits during the late lactation period

Mean change in LW, BCS and carcass fat by the number of lambs reared during the late lactation period are given in Table 4.1. Overall, ewes which reared lambs had greater reductions in LW (4.61 to 7.12kg), carcass fat (1.45 to 2.07kg) and NE (51 to 83 MJ) than ewes with no lambs. In comparison with ewes which did not rear lambs, greater reductions in BCS were observed for ewes which reared triplets (0.47 units) but not for single and twin bearing ewes. There were no differences in the reductions in LW, BCS, carcass fat and NE amongst the group of lamb-rearing ewes during the late lactation period.

4.3 Change in Lamb weights

Mean live weight (LW) and live weight gain (LWG) at different weighing periods, according to the number of lambs reared are presented in Table 4.2. Overall, there was an effect of number of lambs reared by ewes on the total LW ($P = 0.001$) and LWG ($P < 0.001$) of lambs. Total lamb LW increased with the number of lambs reared by ewes at all time periods. Lambs reared as twins and triplets weighed approximately 1.4 and 1.7 times more than singles at each period. Conversely, LWG for lambs reared as singles was approximately 1.8 times greater than the LWG of lambs reared as twins and triplets at all periods, whereas twins and triplets had similar LWG per lamb.

Table 4.2: Mean total live weight (LW; kg ± s.e) and live weight gain (LWG; kg/lamb ± s.e) for lambs reared as singles, twins and triplets at three time intervals during lactation.

Number of lambs reared		1	2	3
N		25	30	10
Period	Day	Total LW (kg)		
Tailing	49	15.33 ± 4.34[a]	21.97 ± 3.79[b]	25.55 ± 5.06[c]
Mid-lactation	63	19.48 ± 4.42[a]	26.69 ± 3.65[b]	32.73 ± 8.02[c]
Weaning	105	28.12 ± 5.56[a]	37.43 ± 5.10[b]	46.96 ± 9.36[c]
Period	Days	LWG (kg/lamb)		
Tailing to mid-lactation	14	4.15 ± 2.19[a]	2.36 ± 1.1[b]	2.39 ± 1.32[b]
Mid-lactation to weaning	42	8.64 ± 2.15[a]	5.37 ± 1.45[b]	4.74 ± 0.76[b]
Tailing to weaning	56	12.79 ± 3.36[a]	7.73 ± 1.93[b]	7.14 ± 1.60[b]

[a, b, c] values within row with different superscripts are different at P <0.05 level of significance

4.4 Ewe performance attributes

4.4.1 Relationship between changes in ewe traits and LW live weight gain (LWG) and weaning weight (WW) of lambs

Comparisons between change in ewe traits with the live weight gain (LWG) and weaning weight (WW) of lambs are given in Tables 4.3 and 4.4, respectively. Overall, correlating the changes in LW, BCS, total carcass fat and NE with the LWG and WW of lambs were poor measures for assessing ewe performance. This was reflected by the occurrence of weak relationships between variables irrespective of the number of lambs reared. Correlations between the changes in ewe traits with LWG (Table 4.4) and WW (Table 4.5) of lambs were generally not significant (P > 0.05). Associations between lean, bone and CW with the LWG and WW of lambs were not investigated as their mean values were similar across time (Figure 4.2).

Although not significant, associations between ewe traits and the LWG of lambs for single and twin-bearing ewes were negative during early lactation period (Table 4.3). The slope of the regression lines for single and twin-bearing ewes during early lactation ranged from -0.07 to -0.3. However, positive associations between all ewe traits and LWG were observed for triplet bearing ewes. The late lactation produced positive regression (slope) and correlation coefficients irrespective of the number of lambs reared by ewes, except for the carcass fat and NE measurements for triplet-bearing ewes (Table 4.3).

Table 4.3: Linear regression and correlations describing the relationship between changes in carcass fat (Car. Fat), lean, BCS, LW and NE measurements of ewes with total live weight gain (LWG) in lambs.

			Early lactation			Late lactation		
Ewe traits	Number of lambs	N	Intercept	Slope	R	Intercept	Slope	R
Car. fat	1	25	19.06	-0.15	-0.07	10.04	0.67	0.50*
	2	30	25.56	-0.23	-0.14	10.97	0.09	0.03
	3	10	43.49	2.11	0.58	13.54	-0.26	-0.17
BCS	1	25	18.84	-2.46	-0.30	9.80	2.53	0.63*
	2	30	26.27	-0.66	-0.08	10.94	0.35	0.05
	3	10	35.63	4.84	0.34	16.15	2.4	0.51
LW	1	25	20.32	0.19	0.3	11.13	0.24	0.51*
	2	30	25.77	-0.08	-0.18	9.67	-0.09	-0.16
	3	10	38.29	0.52	0.59	14.89	0.05	0.12
NE	1	25	18.75	-0.01	-0.12	9.83	0.02	0.50*
	2	30	25.58	-0.01	-0.14	10.98	0.003	0.03
	3	10	42.97	0.05	0.61	13.42	-0.008	-0.20

*significant at 0.05.

Correlations between change in ewe traits and WW of lambs were largely positive at all periods with only a few exceptions that involved triplet-bearing ewes during the late lactation interval (Table 4.4). Therefore, ewes which displayed greater reductions in LW, BCS, carcass fat and NE were associated with lower lamb WW. This was a reflection of positive regression (slope) and correlation coefficients of most ewe traits (Table 4.4).

Table 4.4: Linear regression and correlations describing the relationship between changes in carcass fat (Car. Fat), lean, BCS, LW and NE measurements of ewes throughout lactation with the weaning weight (WW) of lambs.

			Early lactation			Late lactation			Pre-lambing to weaning		
Ewe traits	Number of lambs	N	Intercept	Slope	R	Intercept	Slope	R	Intercept	Slope	R
Car. fat	1	25	28.75	0.09	0.09	31.21	1.54	0.43*	30.10	0.41	0.25
	2	30	38.67	0.11	0.11	38.39	0.37	0.08	39.08	0.22	0.12
	3	10	59.66	0.59	0.59	42.79	-1.59	-0.24	61.86	1.93	0.44
BCS	1	25	27.43	-0.26	-0.26	31.19	6.66	0.65*	30.45	3.24	0.35
	2	30	38.87	0.19	0.19	37.60	0.30	0.03	39.17	1.44	0.16
	3	10	49.43	0.25	0.25	53.70	0.84	0.43	61.26	10.21	0.62
LW	1	25	29.78	0.38	0.47*	31.73	0.35	0.28	32.29	0.28	0.48*
	2	30	38.29	0.08	0.12	38.51	0.10	0.09	41	0.16	0.21
	3	10	53.06	0.57	0.56	44.81	-0.17	-0.09	63.39	0.69	0.59
NE	1	25	28.32	0.03	0.03	30.93	0.04	0.46*	29.97	0.01	0.23
	2	30	28.64	0.11	0.11	38.58	0.01	0.09	39.18	0.01	0.12
	3	10	59.19	0.62	0.62	43.09	-0.04	-0.24	62.47	0.05	0.50

*significant at 0.05 level

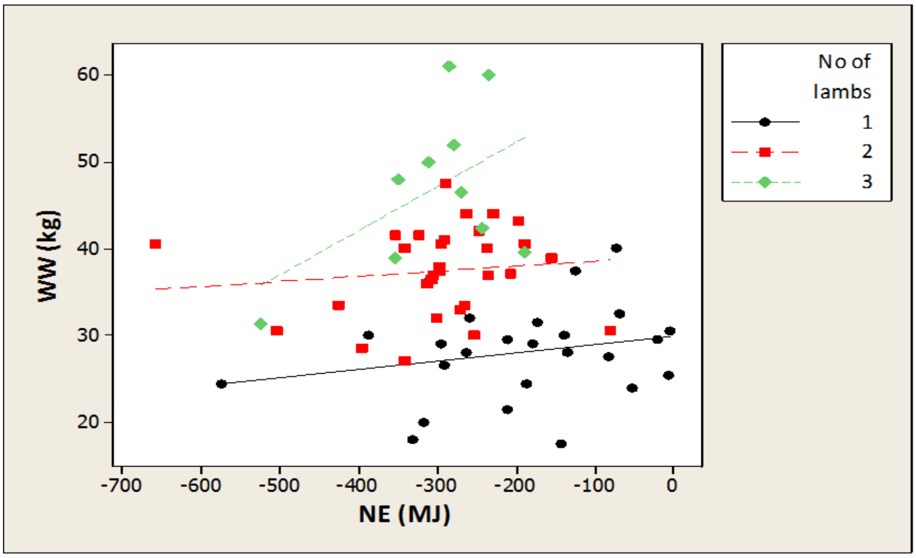

Figure 4.4: Regression describing the relationship between weaning weight (WW; kg) of lambs with change in net energy (NE; MJ) for ewes by number of lambs reared during lactation.

The relationship between lamb weaning weight (WW) and net energy (NE) change in the body of ewes by the number of lambs reared are presented in Figure 4.4. Although not significant, change in NE was positively related with lamb WW for single, twin and triplet-bearing ewes. The slope of the line for the regression lamb WW on change in NE for singletons, twins and triplets during lactation was 0.23, 0.12 and 0.5, respectively (Table 4.3).

4.5 Relationship between LW, BCS and CT measures

The relationship between changes in LW and BCS with CT measures, and LW with BCS at three periods during lactation are given in Table 4.5. All relationships were significant (P <0.05). Overall, LW measures produced stronger correlations than BCS at each of the lactation periods. The early lactation period provided stronger associations than the late interval for both LW and BCS relations. When compared within CT measures, carcass lean consistently provided the weakest correlations for LW and BCS, while associations which involved carcass fat were the strongest.

The regression for LW on BCS at different periods during lactation is also presented in Table 4.3. Overall, a unit change in BCS was equivalent to 12.33 kg change in LW during lactation. Greater changes in LW per unit change in BCS was observed during early lactation compared to late lactation. The regression coefficient for LW on BCS during early lactation was 2.3 times greater than that observed during late lactation.

Table 4.5: Coefficient of determination (R^2; percentage) and regression slopes explaining the relationship between changes in live weight (LW; kg) and body condition score (BCS) with changes in computed tomography (CT; kg) weights for total carcass, carcass fat and lean at three points during lactation.

			ΔLW		ΔBCS	
Period	Measure	N	Slope	R^2	Slope	R^2
Early lactation	ΔLW	74	-	-	8.777	0.30
	ΔCW		0.331	0.55	4.414	0.39
	ΔFat		0.257	0.65	3.504	0.49
	Δlean		0.095	0.22	1.071	0.11
Late lactation	ΔLW	74	-	-	3.849	0.13
	ΔCW		0.238	0.26	1.424	0.09
	ΔFat		0.155	0.27	0.762	0.06
	Δlean		0.086	0.12	0.58	0.05
Pre-lambing to Weaning	ΔLW	74	-	-	12.33	0.70
	ΔCW		0.406	0.73	1.525	0.19
	ΔFat		0.323	0.75	4.119	0.56
	Δlean		0.089	0.27	1.124	0.20

Chapter 5

Discussion

5.1 Tissue mobilisation during lactation

At the start of lactation (pre-lambing), ewes which reared lambs had similar levels of body reserves as predicted from LW, BCS, carcass fat and NE measurements (Table 4.1). This therefore suggests that the number of lambs carried during pregnancy had little effect on tissue reserve level at the start of lactation. This assertion is supported by Lambe et al. (2003a), where the number of lambs nurtured during pregnancy was reported to have no effect on pre-lambing fat and lean tissue levels in the carcass for Scottish Blackface ewes.

The demands of lactation played a key role in the mobilisation of tissue reserves, and effect which became more profound with an increasing number of lambs reared. Ewes which did not rear lambs had similar measurements (LW, BCS, carcass fat, lean, bone and NE) at pre-lambing, mid-lactation and weaning. However, significant declines in LW, BCS, carcass fat and NE were evident for lamb-rearing ewes with time (Figures 4.1, 4.2 and 4.3). At the end of lactation (pre-lambing to weaning), LW and BCS declined by at least 140 grams per day and 1 unit for ewes which reared lambs, respectively. Likewise, carcass fat and NE for lamb-rearing ewes decreased by at least 46 grams and 1.9 MJ per day during lactation. The use of ewes which did not rear lambs (the control group made) it possible to estimate how much of the reductions in LW, carcass fat and NE was due to lactation. Holding the effects of gut-fill, fleece weight, metabolism and animal mobility indicative to animals which did not rear lambs, it can be argued that approximately 60 to 70%, 75 to 84% and 72 to 82% of the total changes observed in LW, carcass fat and NE was used to maintain lactation, respectively. The lower values for each measure were associated with ewes which reared one lamb, while higher for twin and triplet-bearing mothers.

The changes in LW, BCS and NE observed in the current study were largely a consequence of carcass fat depletion during lactation. This was reflected by fat being the only tissue in the carcass of ewes which showed marked reductions in CT weights with time, more so for ewes which reared twins and triplets. At weaning carcass fat weight on average declined by 43 and 78% of pre-lambing weights, where the lower value (43%) was associated with single-bearing ewes, while higher for twins and triplets. This suggests that the contribution of lean and bone tissue towards lactation was negligible, and fat was the main tissue in the carcass of sheep involved in sustaining animal production. This finding is consistent with Cowan et al. (1980) and Lambe et al. (2003a), where adipose tissue was documented as the most labile and reliable source of energy during lactation.

Lamb-rearing ewes were in a negative energy state during the early and late lactation periods, as seen by declines in LW, BCS, carcass fat and NE (Figures 4.1, 4.2 and 4.3). Previous studies have reported declines in LW, BCS and carcass fat during the early lactation period, and increases during the late lactation interval (Borg et al., 2009; Corner-Thomas et al., 2015; Lambe et al., 2003a). The continuous reductions in LW, BCS, carcass fat and NE observed in the current study indicates that ewes which reared lambs mobilised energy reserves throughout lactation. This finding is not in agreement with Lambe et al. (2003a), Borg et al. (2009) and Corner-Thomas et al. (2015). The difference in the pattern of tissue mobilisation between studies can be attributed to climatic variability (low levels of precipitation) which, in the case of the current study, induced low levels of pasture supply and quality during lactation (Bywater & Moot, 2011; Litherland & Lambert, 2007; Valentine & Kemp, 2007) which is reflected in the zero live weight increase in ewes that reared no lambs and presumably were without increased nutritional demand for lactation. In the current study, there was a high dependence on precipitation as ewes grazed on ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) pastures out in the field under normal farming conditions. Surprisingly, the continuous reductions for carcass fat was not sufficient to induce significant declines in lean tissue and carcass weight (CW). This finding is not in agreement with Lambe et al. (2003a), where severe depletion of fat in the carcass of Scottish Blackface sheep was related to the depletion of lean tissue reserves (Lambe et al., 2003a). Given the considerable extent to which mobilisation of fat occurred in multiple bearing ewes in this study, the present results do not appear to support the notion that lean tissue catabolism occurs once adipose levels reach a critical level.

5.2 Relationship between change in LW with BCS

The association between LW and BCS throughout lactation (pre-lambing to weaning) was positive and linear, with one unit change in BCS being equivalent to 12.33 kg change in LW. (Table 4.5). This finding is consistent to conclusions made in several studies involving ewes in varying physiological states (Caldeira & Portugal, 1991; Frutos et al., 1997; Jefferies, 1961; Oregui et al., 1997; Özder & Karadağ, 2008; Russel et al., 1969; Sezenler et al., 2011; Teixeira et al., 1989; Treacher & Filo, 1995; Van Burgel et al., 2011). However, the regression coefficient reported in the current study was higher than those reported in the literature. There is evidence indicating that sheep which exhibit greater LW change per unit change in BCS are either mobilising water and body reserves faster than animals maintaining weight (Caldeira & Portugal, 1991; Oregui et al., 1997). Therefore, the high regression coefficient observed in this study was expected as the study population was in a negative energy state and mobilising tissue reserves induced by demands imposed by lactation.

The change in LW observed in this study was more responsive to change in BCS during early lactation compared with the late lactation interval. Overall, reductions in LW per unit change in BCS was 2.3

times (8.78 verses 3.85) greater during the early compared with the late lactation period (Table 4.5). This was expected as the early lactation period in sheep has been reported to be associated with marked depletion of body reserves, while the late lactation with the replenishment of body reserves (Borg et al., 2009; Lambe et al., 2003a). Examination of the coefficient of determination (R^2) showed that only 30 and 13% of the changes in LW was predicted by variation in BCS during early and late lactation, respectively (Table 4.5). The R^2 explaining the relationship between LW and BCS in this study were lower than Özder and Karadağ (2008), Sezenler et al. (2011) and Oregui et al. (1997) at pre-lambing and weaning. Therefore, it can be argued that the finding reported here cannot be accepted with confidence as most of the variation in the relationship for LW and BCS was due to extrinsic factors, such as gut-fill and animal frame size.

5.3 Lamb growth

Lamb LW increased with time and was dependent on the number of lambs reared by ewes (Table 4.2). Overall, lambs which were reared as singles grew faster than their twin and triplet counterparts throughout lactation, while those reared as twins and triplets grew at similar rates. This was expected since lambs reared as singles are not exposed to competition for their mother's milk. Nonetheless, lamb LWG reported in the current study was below the commonly targeted growth rates (300grams LW/day and above) from birth to weaning on commercial farms (Bywater & Moot, 2011; Grigg, Grigg, & Lucas, 2008; Muir, Smith, & Lane, 2003). It is important to highlight that the lamb LWG observed in this study occurred from tailing to weaning, with the low growth rates being a consequence of shortages in feed supply induced by climatic variability. The lamb growth rates observed in this study were 228, 138 and 127 g per day for lambs reared as singles, twins and triplets, respectively. Not surprisingly, total LW of lambs significantly increased with the number of lambs reared as singles, twins and triplets (Table 4.2). The differences in total LW observed between lambs raised as singles, twins and triplets were similar to that observed by Mathias-Davis et al. (2011), where the total weight of lambs reared as twins and triplets on average were 1.5 and 1.8 times greater than singles at pre-lambing and weaning, respectively. However, the mean pre-lambing and weaning weights reported by Mathias-Davis et al. (2011) were higher than those observed in this study and can be attributed to greater LWG from a different breed of sheep.

5.4 Lactation performance of ewes

LWG and WW of lambs was not reflected by the mobilisation of expenditure of energy reserves for ewes during lactation. This was evident by weak correlations between change in LW, BCS, carcass fat and NE with the LWG and WW of lambs for majority of the comparison shown in Table 4.3 and 4.4. These findings are in agreement with previous research which involved the use of LW and BCS (Gibb

& Treacher, 1980; Litherland et al., 1999), where the mobilisation of body reserves was reported to have no effect on the growth rate of lambs. It can be extrapolated from the associations for LW and BCS that, in addition to carcass fat, the mobilisation of total fat reserves (sum of internal and carcass fat) during lactation did not have an influence on the LWG and WW of lambs.

Taken together, the current study indicates that the mobilisation of tissue reserves as a metabolic adaptation for galactopoiesis is a poor measure for assessing the lactation performance of ewes measured through the LWG and WW of lambs. Nonetheless, ewes which mobilised more tissue reserves produced lower LWG and WW for lambs. However, it is important to highlight that single and twin-bearing ewes which mobilised more energy reserves during early lactation were associated with slightly greater LWG of lambs (Table 4.3). This indicates that, although not significant, there may be some benefits in encouraging single and triplet-bearing ewes to mobilise body reserves during the early lactation period. Unfortunately, this benefit was not sufficient to carry-over to the end of lactation as ewes which mobilised more energy reserves during lactation (pre-lambing to weaning) weaned lighter lambs (Table 4.4).

There are a variety of studies indicating that there is a significant effect of tissue mobilisation by ewes during lactation on the LWG and WW of lambs using LW and BCS (Borg et al., 2009; Kenyon et al., 2009; Mathias-Davis et al., 2013; Mathias-Davis et al., 2011; Scobie et al., 2016; Sejian et al., 2010). Inconsistencies between previous studies and the current are probably due to differences in sample size and protocol used. In the aforementioned studies much larger sample sizes were used, except for Sejian et al. (2010) where ewes were housed in sheds under controlled grazing conditions. In addition, the use of an adjusted pre-lambing LW for ewes and lack of lamb birth weights in this trial may have contributed to contrasting conclusions between studies.

5.5 Accuracy of LW and BCS in predicting tissue reserves in ewes

Change in LW appeared to be more accurate than BCS in predicting change in soft tissue (fat and lean) reserves during lactation. This was reflected in LW consistently producing higher coefficient of determination (R^2) values than BCS at all periods during lactation for ewes (Table 4.5). These observations are not in agreement with several studies where BCS was reported to be superior over LW in estimating soft tissue reserves in sheep (Delfa et al., 1989; Frutos et al., 1997; Oregui et al., 1997; Russel et al., 1969; Teixeira et al., 1989; Van Burgel et al., 2011). The differences in accuracy between those studies and the current is probably due to differences in the physiological state of ewes and protocol used to form the relationships. In the studies mentioned above ewes were not in a lactating state and LW and BCS measures were compared to the weights and/or chemical content of dissected tissues. The R^2 values observed for LW in this study were within the range reported for fat deposits in the literature. For accuracies associated with BCS, those observed in the current study were lower than reported in the literature for non-lactating animals, but within the range described for lactating ewes (Table 2.1). The early lactation interval can be distinguished by better prediction of soft tissue reserves and CW by both LW and BCS compared to the late period. This was evident by the observation of stronger R^2 values for both LW and BCS during early lactation than the late lactation interval (Table 4.5). These findings indicate that changes in total fat, lean tissue and CW were more closely associated with LW and BCS measurements during the early lactation interval.

Chapter 6
Conclusion

Despite the continuous reductions in LW, BCS, carcass fat and NE, mobilisation of tissue reserves by lamb-rearing ewes was poorly related with the LWG and WW of lambs during lactation. Ewes which mobilised more body reserves were associated with lambs of slightly lower WW. The mobilisation of body reserves by ewes was influenced by the number of lambs reared. Ewes which reared lambs lost considerably more body condition than ewes which did not rear lambs. As a result, lactation was deemed to play a key role in the mobilisation of carcass fat reserves. Reductions in LW, BCS and NE was largely a consequence of carcass fat depletion as muscle and bone tissue weights remained constant throughout lactation. At the end of lactation, twin and triplet bearing ewes mobilised considerably more carcass fat than single-bearing mothers, while twins and triplets had similar levels of carcass fat weight loss.

It was found that ewes which reared lambs were in a negative energy state during the early and late lactation periods. This could be attributed to low pasture supply and quality as a result of lower than average rainfall during the study period. Lamb LWG in this study was lower than commonly targeted growth rates in pastoral systems. As a result, lamb WW was lower than that reported in the literature. Notwithstanding, the results showed that lambs reared as singles grew faster than those reared as twins and triplets.

The results of this study do not support the theory which asserts that ewes which mobilise more body reserves during lactation are associated with greater lamb WW. However, the findings are not generalisable owing to relatively small sample sizes and poor associations between the mobilisation of tissue reserves by ewes and lamb LWG and WW. The findings of this study should be interpreted with caution, as both ewe and lamb data were recorded for one production season. A key limitation of this study was the lack of lamb birth weight data to help better explain associations between ewe traits and lamb WW. Also, in the absence of pasture growth data it was not possible to account for the effects of feed supply on the mobilisation of energy reserves for ewes and lamb LWG during lactation. Therefore, there is need for further research across more production seasons that takes into account measurements for lamb LW at birth and pasture availability.

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